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ORIGINAL PAPER

Metabolic and surgical predictors in horseshoe and pelvic ectopic kidneys

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Summary

Background: *Horseshoe kidney (HSK) and pelvic ectopic kidney (PEK) are congenital anomalies linked to impaired urinary drainage and a higher risk of nephrolithiasis. Evidence regarding metabolic profiles and surgical outcomes in these groups remains sparse. This study assessed predictors of postoperative stone clearance and 12-month recurrence in patients with HSK and PEK undergoing endourological procedures intervention.*

Methods: *We conducted a retrospective analysis of 50 consecutive patients with CT-confirmed HSK or PEK treated with retrograde intrarenal surgery (RIRS) or mini-percutaneous nephrolithotomy (mini-PNL) over 12 months. All patients had a standardized 24-hour metabolic evaluation and imaging follow-up at 1, 6, and 12 months. Outcomes included stone-free status at one month and recurrence at one year. Predictors were assessed using univariable and multivariable logistic regression.*

Results: *Stone-free status at 1 month was achieved in 62% of patients, with 22% having residual fragments ≥ 4 mm. Residual burden was strongly associated with recurrence, which occurred in 44% of the cohort. Patients with fragments ≥ 4 mm had the highest recurrence rate (72.7%), compared with 35.5% among stone-free individuals (p = 0.047). Age was independently associated with reduced likelihood of achieving stone-free status (B = -0.069, p = 0.011). Higher 24-hour urinary volume was the only biochemical parameter protective against recurrence (OR 0.243, p = 0.039). Neither malformation type nor surgical technique significantly influenced postoperative outcomes or recurrence. Metabolic abnormalities were frequent but not predictive of stone type or recurrence.*

Conclusions: *In HSK and PEK, postoperative residual fragments and low urine volume are the main determinants of recurrence, whereas anatomical subtype and surgical approach have limited prognostic value. Strategies focused on complete stone clearance and hydration optimization may improve long-term outcomes in this patient population.*

KEY WORDS: Horseshoe kidney; Pelvic ectopic kidney; Nephrolithiasis; Metabolic evaluation; Stone recurrence.

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INTRODUCTION

Congenital anomalies of the kidney and urinary tract (CAKUT) represent a diverse group of structural malformations with significant implications for renal physiology and urological health. *Horseshoe kidney* (HSK) and *pelvic ectopic kidney* (PEK) are two of the most frequently encountered entities, resulting from disrupted embryologic ascent and fusion processes (1, 2). These anomalies alter calyceal orientation, impair urinary drainage, and predispose to recurrent infections and nephrolithiasis (3).

The prevalence of kidney stones in patients with HSK and PEK is notably higher than in the general population, with estimates ranging from 20% to 60% depending on diagnostic criteria and imaging modality (4, 5). Anatomic factors, such as malrotation, ureteropelvic obstruction, and aberrant vasculature, contribute to urinary stasis and compromise the effectiveness of standard surgical approaches (6).

While *retrograde intrarenal surgery* (RIRS) has gained popularity due to its minimally invasive nature, its efficacy in the setting of congenital anomalies is limited by altered anatomy and restricted access to calyces (7). In contrast, *percutaneous nephrolithotomy* (PNL) provides higher *stone-free rates* (SFR), particularly for complex or larger stones, albeit with a higher morbidity profile (8, 9). Emerging data suggest that laparoscopy and robotic-assisted techniques may offer additional tools for selected patients with challenging anatomy (10).

Metabolic factors also play a significant role in stone formation, with hypercalciuria, hypocitraturia, and hyperoxaluria frequently reported among stone formers (11, 12). However, metabolic data specific to HSK and PEK populations remain limited, and it is unclear whether these anomalies confer unique biochemical risk profiles (13). Stone recurrence is particularly concerning in these patients due to impaired drainage and fragment clearance (14).

This study aims to assess the surgical and metabolic outcomes in a well-defined cohort of patients with HSK and PEK, with a focus on predictors of postoperative clearance and stone recurrence.

MATERIALS AND METHODS

This retrospective observational study included 50 patients with congenital renal malformations and associated urolithiasis who underwent surgical treatment in a single tertiary urology center over a continuous 12-month period. All anatomical anomalies were confirmed preoperatively by

contrast-enhanced CT urography, with MRI reserved for patients in whom iodinated contrast was contraindicated. Stone composition was determined by Fourier-transform infrared spectroscopy of intraoperatively retrieved fragments.

Patients were included if they had a CT-confirmed diagnosis of HSK or PEK, at least one renal stone requiring active intervention, a predefined 24-hour urinary metabolic profile, and at least 12 months of imaging follow-up. Patients were excluded if the metabolic assessment was incomplete, if they had an active urinary tract infection during the metabolic work-up, or if they had a documented systemic disorder known to affect stone formation, including primary hyperparathyroidism or cystinuria.

All patients underwent a standardized metabolic evaluation based on a 24-hour urine collection, which included measurements of urinary volume, calcium, oxalate, citrate, uric acid, and urinary pH. Serum uric acid levels were obtained on the same day as the urine sample. Metabolic abnormalities were defined according to standard reference values used in 24-hour urine analysis. Hypercalciuria was defined as urinary calcium > 250 mg/24 h in women or > 300 mg/24 h in men. Hyperoxaluria corresponded to urinary oxalate > 45 mg/24 h. Hypocitraturia was defined as urinary citrate < 320 mg/24 h. Hyperuricosuria was defined as uric acid > 750 mg/24 h in women or > 800 mg/24 h in men (11).

In addition to solute-specific metabolic abnormalities, two lithogenic parameters were systematically recorded and analyzed: 24-hour urinary volume and urinary pH. Low urinary volume was defined as < 1.5 L per 24 hours. Low urinary pH was defined as pH < 5.4, a threshold associated with uric acid supersaturation in standard metabolic stone evaluation (12, 14).

Urine collections followed a uniform protocol that provided written instructions on diet and hydration and included verification of completeness upon return to limit day-to-day variation. The protocol used to minimize inter-individual variability is detailed in Appendix 1.

Surgical management consisted of either RIRS or *miniaturized PNL* (mini-PNL), selected based on stone size, location, and the feasibility of endoscopic access determined by the underlying renal anomaly. RIRS was performed using flexible digital ureteroscopes in combination with holmium laser lithotripsy, with all procedures carried out under general anesthesia in the lithotomy position. Mini-PNL was conducted through a sub-20 Fr tract obtained under fluoroscopic guidance, using controlled dilation and a mini-nephroscope system. Stone fragmentation was achieved using pneumatic or ultrasonic lithotripsy, depending on equipment availability and surgeon preference.

Stone clearance was assessed using a standardized low-dose non-contrast CT protocol performed one month after surgery. Residual stone burden was classified into three categories: stone-free, residual fragments measuring ≤ 4 mm, and fragments > 4 mm. Measurements were based on the largest diameter of any identifiable fragment; in cases with multiple fragments, classification was determined by the largest one. All CT scans were reviewed by an experienced urologist, with radiological confirmation obtained when findings were equivocal.

Recurrence was defined as the appearance of new stones on scheduled imaging or the occurrence of clinically confirmed stone-related events during follow-up. These events included documented renal colic, new-onset obstruction, or urinary tract infection attributed to calculi based on clinical or imaging findings. The follow-up schedule included renal ultrasound at 6 and 12 months, with non-contrast CT reserved for symptomatic patients or when ultrasound could not reliably exclude small residual fragments or early obstruction.

Statistical analysis was conducted using IBM SPSS Statistics version 26. The distribution of continuous variables was assessed with the Shapiro-Wilk test. Normally distributed variables were reported as means and standard deviations, while non-normally distributed variables were summarized as medians and interquartile ranges; in both cases, minimum and maximum values were provided. Categorical variables were described using frequencies and valid percentages. Missing data were minimal and addressed through case-wise deletion.

Group comparisons were performed using Pearson's Chi-square test or Fisher's exact test, where appropriate, based on expected cell frequencies. Postoperative outcomes were analyzed either as a binary endpoint (stone-free vs. any residual fragment) or as an ordinal, three-level variable (stone-free, residual fragments ≤ 4 mm, residual fragments > 4 mm), depending on the analytical framework. Binary and ordinal logistic regression models were used to identify predictors of postoperative stone clearance and 12-month recurrence. Variable selection followed a predefined enter method, and multicollinearity was assessed using tolerance and *variance inflation factor* (VIF) values. Model performance was evaluated using the -2 log-likelihood, Nagelkerke R^2, and the Hosmer-Lemeshow goodness-of-fit test. For binary models, discriminatory ability was assessed using *receiver operating characteristic* (ROC) analysis and the *area under the curve* (AUC). Statistical significance was defined as a p-value < 0.05, while values between 0.05 and 0.10 were interpreted as suggestive but not conclusive.

Results

Baseline demographic and clinical characteristics

Out of the 50 patients included in the study cohort, a substantial majority were male (74%), indicating a clear gender asymmetry. All cases included in the analysis had confirmed structural anomalies, with HSK slightly more prevalent (58%) than PEK (42%). The sample size was evenly distributed between the two anomaly types with respect to other baseline variables, suggesting no initial systematic bias.

As illustrated in Table 1, the clinical parameters show a relatively homogenous metabolic profile, albeit with a wide interindividual dispersion. No missing data were recorded, and all 50 patients had complete metabolic and postoperative follow-up data, allowing for full-case analysis without the need for imputation strategies.

Procedural outcomes

All patients underwent surgical treatment for stone disease, most commonly through RIRS, as shown in Table 1. Mini-

Table 1.
Baseline demographic, anatomical, metabolic, and clinical characteristics of the study population.

Variable	Category	N (%)
Sex	Male	37 (74.0%)
	Female	13 (26.0%)
Renal malformation type	HSK	29 (58.0%)
	PEK	21 (42.0%)
Surgical intervention	RIRS	40 (80.0%)
	mini-PNL	10 (20.0%)
Stone composition	Calcium oxalate (CaOx)	31 (62.0%)
	Mixed CaOx + CaP	7 (14.0%)
	Uric acid	7 (14.0%)
	Calcium phosphate (CaP)	5 (10.0%)
Metabolic abnormalities	Hypercalciuria	24 (48.0%)
	Hyperoxaluria	14 (28.0%)
	Hypocitraturia	13 (26.0%)
	Hyperuricosuria	9 (18.0%)
Recurrent UTIs	Present	14 (28.0%)
Postoperative SFR status	Stone-free	31 (62.0%)
	Residual ≤ 4 mm	8 (16.0%)
	Residual ≥ 4 mm	11 (22.0%)
Recurrence at 12 months	Yes	22 (44.0%)
	No	28 (56.0%)

PNL was performed in fewer cases, generally in patients with larger stones that would likely have required more than one flexible ureteroscopy session.

Stone-free status was achieved in just over half of the patients, while the remainder had either small, clinically insignificant fragments or larger residual ones detectable on follow-up imaging.

Although descriptive data suggested a higher clearance rate in the mini-PNL group (80% *vs.* 57.5% for RIRS), this difference did not reach statistical significance (p = 0.262), likely due to the small sample size and procedural allocation bias.

The presence of residual stone fragments, particularly those exceeding 4 mm, was associated with an increased likelihood of recurrence during follow-up, as will be detailed in the following subsection. It is noteworthy that residual fragments ≤ 4 mm were observed exclusively in patients treated with RIRS, which may reflect differences in fragmentation efficacy or intraoperative visualization.

A comprehensive schematic of the study structure, from inclusion to endpoint evaluation, is presented in Figure 1.

Association between stone composition and metabolic abnormalities

Among patients with uric acid stones, hyperuricosuria was more frequent (42.9%) than among those with calcium oxalate stones (12.9%). Although a numerical difference was observed, the association did not reach statistical significance (Pearson's Chi-square, p = 0.164), a result likely attributable to the limited sample size rather than a true absence of effect. Similarly, hyperoxaluria was most frequent in patients with pure calcium oxalate stones (38.7%) and was not identified in those with uric acid stones. While the trend appeared consistent, statistical significance was not achieved (p = 0.151), though the likelihood ratio (p = 0.067) suggested a near-significant association.

Low urinary volume was identified in 16% of patients, predominantly among those with calcium oxalate and uric acid stones. In contrast, markedly acidic urine was observed in 6 of 7 patients with uric acid stones (85.7%), whereas no cases were observed in any other stone category. Because of the low expected frequencies, Fisher's exact test was used, revealing a very strong link between uric acid stones and acidic urine (p < 0.000001).

Hypocitraturia was most prevalent in calcium oxalate stone formers (35.5%), but the association was not statistically significant (p = 0.212). With a uniform distribution across stone types (40-52%), hypercalciuria emerged as a non-specific finding, unlikely to aid in differentiating stone composition within this population.

Although 14 patients had a history of recurrent urinary tract infections, all preoperative urine cultures were negative at the time of intervention, as procedures were postponed until microbiological clearance. No struvite stones were detected. All calcium phosphate stones were hydroxyapatite, including the phosphate component of mixed CaOx + CaP stones, with no brushite or infection-related apatite profiles identified. Detailed distribution of

Figure 1.
Study design.

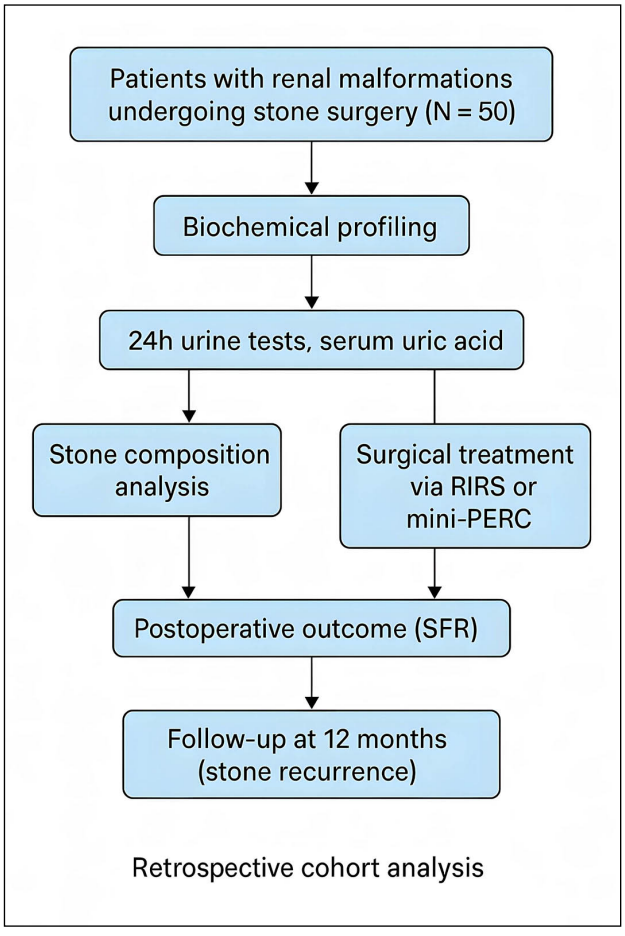


Table 2.
Distribution of urinary metabolic abnormalities by stone type.

Stone type	Hypercalciuria n (%)	Hyperoxaluria n (%)	Hypocitraturia n (%)	Hyperuricosuria n (%)	Low urinary volume n (%)	Low urinary pH (pH < 5.4) n (%)
CaP	2/5 (40.0%)	1/5 (20.0%)	1/5 (20.0%)	0/5 (0.0%)	0/5 (0.0%)	0/5 (0.0%)
CaOx	16/31 (51.6%)	12/31 (38.7%)	11/31 (35.5%)	4/31 (12.9%)	5/31 (16.1%)	0/31 (0.0%)
Uric acid	3/7 (42.9%)	0/7 (0.0%)	1/7 (14.3%)	3/7 (42.9%)	2/7 (28.6%)	6/7 (85.7%)
Mixed CaOx+CaP	3/7 (42.9%)	1/7 (14.3%)	0/7 (0.0%)	2/7 (28.6%)	1/7 (14.3%)	0/7 (0.0%)
Total	24/50 (48.0%)	14/50 (28.0%)	13/50 (26.0%)	9/50 (18.0%)	8/50 (16.0%)	6/50 (12.0%)

metabolic abnormalities by stone composition is presented in Table 2 below.

Predictors of postoperative outcome and stone recurrence

At one-month follow-up, complete stone clearance was achieved in 62% of patients. The presence of residual fragments ≥ 4 mm was strongly associated with an unfavorable postoperative profile and represented a clinically relevant predictor for subsequent stone recurrence. Postoperative outcomes were not significantly affected by malformation type (p = 0.890) or surgical technique (p = 0.670) in univariate analysis (Table 3).

Multivariate analysis identified age as the only independent predictor of stone-free status, with older age associated with reduced likelihood of complete clearance (B = -0.069, p = 0.011).

At 12-month follow-up, 44% of patients experienced stone recurrence, as defined by either radiological evidence of new stones or clinical events attributed to lithiasis.

Table 3.
Univariable analysis of predictors associated with recurrence.

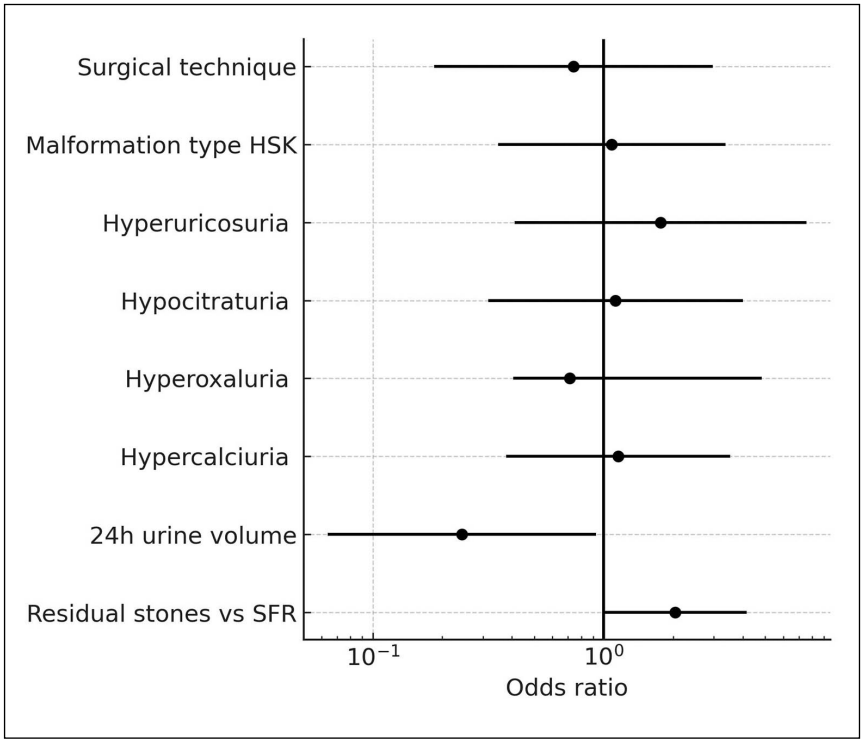
Predictor	P-value
Residual stones vs. stone-free	0.051
24h Urine volume	0.039
Hypercalciuria	0.802
Hyperoxaluria	0.595
Hypocitraturia	0.856
Hyperuricosuria	0.444
Malformation type	0.890
Surgical technique	0.670
Age	0.761

Recurrence was strongly influenced by postoperative stone status: the lowest rate (35.5%) was observed in stone-free patients, while the highest (72.7%) was observed in patients with residual fragments ≥ 4 mm (p = 0.047). Although the recurrence risk was comparatively lower, patients with residual fragments ≤ 4 mm still demonstrated an elevated likelihood of recurrence.

Binary logistic regression confirmed that postoperative stone status was an independent predictor of recurrence (OR = 2.04, p = 0.051), with a near-significant p-value.

Importantly, 24-hour urinary volume emerged as the only significant biochemical predictor, with higher volumes associated with a reduced likelihood of recurrence (OR = 0.243, p = 0.039). None of the other metabolic variables (Figure 2) showed significant associations with recurrence in either univariate or multivariable analyses. Additionally, neither the type of malformation nor the type of surgical approach was associated with recurrence at 12 months. Age was also analyzed as a continuous predictor of recurrence. The average age did not differ significantly between patients with and without recurrence (p = 0.761), and the variance was consistent.

Figure 2.
Forest plot of predictors for recurrence.



Correlations between biochemical urinary parameters

The interrelationships between urinary biochemical variables were assessed using both parametric and non-parametric correlation coefficients. No statistically significant correlations emerged from either method, and all observed coefficients were weak, with absolute r or p values consistently below 0.20.

Specifically, 24-hour urinary volume demonstrated no meaningful association with the excretion of calcium, oxalate, citrate, or uric acid, nor with urinary pH.

Likewise, no significant linear or monotonic relationships were identified between urinary calcium and oxalate, or between citrate and uric acid, suggesting that these solutes vary independently within the cohort.

Discussion

The surgical treatment of nephrolithiasis in patients with congenital renal anomalies, particularly HSK and PEK, remains a nuanced clinical challenge due to altered anatomy, atypical calyceal distribution, and impaired drainage. Our findings align with the broader literature in underscoring that while both RIRS and PNL are feasible, their efficacy is context-dependent and should be guided by anatomical and stone-related factors.

RIRS has emerged as a preferred approach for select patients with HSK due to its minimally invasive nature and lower complication profile. *Bansal et al.* reported that flexible ureteroscopy in HSK achieved acceptable SFRs for stones ≤ 20 mm, though operative times were longer and access to upper-pole calyces was frequently limited (15). Similarly, *Lavan et al.* found that stone clearance in HSK was significantly affected by the degree of renal malrotation, with lower pole calculi being more difficult to access via ureteroscopy (16). These anatomical constraints contribute to higher retreatment rates and explain why complete clearance in a single session is often elusive (17).

In contrast, PNL offers the advantage of direct access to renal cavities and is particularly effective for large or complex calculi. *Zhiqiang et al.* demonstrated that modified PNL techniques in HSK achieved an SFR of 85.3% with acceptable morbidity, highlighting the importance of precise calyceal puncture planning using fluoroscopic and ultrasonographic guidance (18). *Khadgi et al.* further reported that mini-PNL in anomalous kidneys resulted in fewer complications compared to standard PNL, without compromising efficacy (19). Notably, ultrasound-guided puncture and tract dilation have been shown to reduce the risk of injury to aberrant vessels in HSK (20).

PEK presents a different set of challenges, primarily due to its low pelvic position and anterior rotation. *Wu et al.* reported that RIRS in PEK is limited by ureteral angulation and reduced working space, resulting in incomplete stone access (21).

For this reason, laparoscopic pyelolithotomy has gained traction in PEK cases where both stone burden and anatomy preclude effective RIRS or PNL (22).

Stone recurrence is a major concern, particularly in cases with residual fragments postoperatively. *Purkait et al.* demonstrated that residual fragments > 4 mm in anomalous kidneys were associated with a twofold increase in recurrence at 12 months, underscoring the importance of complete clearance (23). Our findings support this observation, indicating that residual burden is a significant predictor of recurrence.

Metabolic abnormalities also raise the risk of recurrence. According to the work of *Duvdevani and colleagues*, a significant number of patients with congenital renal anomalies exhibit at least one metabolic disturbance, most often hypercalciuria or hypocitraturia (24). Notably, metabolic risk was independent of anatomical anomaly, underscoring the need for systematic biochemical screening in all stone formers, regardless of structural abnormality (25).

Urinary volume was the only metabolic parameter significantly associated with recurrence in our cohort, corroborating the findings of *Daudon et al.*, who reported that patients with daily urine output < 2 L had substantially higher recurrence rates, even when stone-free initially (26).

Interestingly, neither the type of malformation nor surgical modality was a significant predictor of recurrence in multivariate models, supporting the view that anatomical

Declarations

Ethical approval and consent for participate: *Ethical approval for this retrospective study was obtained from the Ethics Committee of "Prof. Dr. Theodor Burghele" Clinical Hospital in Bucharest (approval no. 8506 / 09/05/2024).*

Consent for publication: *Not applicable.*

Availability of data and material: *The datasets generated and analyzed during this study are not publicly available because of patient privacy and institutional data protection policies. However, they can be obtained from the corresponding author upon reasonable request.*

Competing interests: *The authors declare that they have no competing interests.*

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Authors' contributions: *SR: study concept and design, data collection, surgical data acquisition, critical revision of the manuscript. OCN: study design, data curation, statistical analysis, interpretation of results, manuscript drafting. TMP: imaging review, validation of surgical classifications, contribution to manuscript writing and editing. DLB: metabolic data acquisition and verification, contribution to data interpretation, manuscript editing. GSP: clinical data collection, database management, and contribution to manuscript revision. VJ: supervision, methodological guidance, validation of final analyses, and critical review of the manuscript.*
All authors have read and approved the final version of the manuscript and accept responsibility for all aspects of the work.

Further information: *This work is part of the research project "Importanţa analizei compoziţiei calculilor renali în prevenirea recurenţei litiazice pe rinichii ce asociază malformaţii congenitale" ("The importance of kidney stone composition analysis in preventing recurrence in patients with congenital renal malformations"), funded by the Academy of Romanian Scientists (AOSR), Bucharest, Romania.*

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anomaly alone is not a sufficient risk stratifier. This aligns with a study by *Shpitzer et al.*, which emphasized the multifactorial nature of recurrence and advocated for risk-adapted surveillance strategies (27).

Conclusions

In the light of our findings and the current literature, a stratified treatment algorithm is warranted: RIRS remains ideal for small, accessible stones; PNL (preferably mini-PNL) should be considered for larger or lower-pole stones; and laparoscopic interventions should be reserved for select PEK cases. Adjunct metabolic evaluation and structured follow-up are indispensable to long-term success (28, 29).

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Appendix 1

A. Standardized 24-hour urine collection protocol

1. Patient instructions

Patients were asked to maintain their usual diet during the three days preceding the collection and to avoid abrupt changes in salt or protein intake. Foods with very high oxalate content, such as spinach, rhubarb, nuts, and chocolate, were discouraged on the collection day. Alcohol was avoided for at least 12 hours before starting the collection. Vitamin C supplements exceeding 500 mg per day, calcium supplements, and vitamin D were not permitted during the 24-hour interval.

Patients were instructed to maintain their usual daily fluid intake, generally 1.5 to 2.5 liters, without intentional overhydration. Marked increases or decreases in fluid intake were avoided. No restrictions were placed on the types of fluids routinely consumed, except for alcoholic beverages.

Regular medications were recorded. Diuretics were maintained if clinically indicated and documented. Physical activity during the collection day was kept at the patient's usual level, while strenuous exercise was avoided to prevent fluctuations in urine volume and pH.

2. Collection procedure

The 24-hour interval began after discarding the first morning void. All subsequent urine was collected in a single container, including the first void of the following morning. Patients were instructed to note the start and end times and to report any missed samples. The container was kept in a cold environment until it was returned to the clinic.

Upon return, a nurse verified the completeness of each collection by confirming the recorded start and end times, discussing any missed voids, and assessing whether the reported volume was consistent with a typical 24-hour output. Collections with very low volumes (< 300-400 mL) or unusually high volumes (> 4 L) were flagged for repeat testing. In selected cases, 24-hour urinary creatinine was also reviewed to support completeness assessment.

B. Sample handling and laboratory processing

All urine and serum samples were processed according to a uniform laboratory workflow to ensure analytical consistency across the cohort.

Upon arrival, each 24-hour urine container was gently mixed to ensure homogeneity. A recorded aliquot was then transferred into standardized sterile tubes. Samples were stored at 4°C and transported to the central laboratory immediately. Urine pH was measured within one hour of arrival to reduce drift caused by temperature changes or bacterial growth. Serum samples used for uric acid measurement were collected on the same day and processed within two hours.

Urinary calcium, oxalate, citrate, and uric acid were quantified using validated enzymatic or spectrophotometric assays, depending on the laboratory's standard platform. All assays were performed in the same laboratory to avoid inter-laboratory variability. Calibration curves were generated daily, and internal controls were run with each batch of samples. Urinary volume was recorded directly from the 24-hour container, and excretion values were expressed as mg/24h. Urine pH was measured by a calibrated potentiometric meter.

The laboratory followed an internal quality assurance system with regular verification of reagent stability, equipment calibration, and reference range checks. For oxalate and citrate, which are more prone to analytical fluctuations, duplicate measurements were performed when borderline or inconsistent results were obtained. Measurements falling outside expected physiological ranges were reviewed by a laboratory specialist before validation.